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An Introduction to Science Learning

How Children Learn Science

Science is constructed of facts, as a house is of stones. But a collection of facts is no more a science than a heap of stones is a house.

Henri Poincaré

LAURA'S SECOND GRADE CLASSROOM*

Laura was ready to begin teaching a second grade unit on light and shadows. She began by reading the first two verses of a poem to her class.

MY SHADOW

I have a little shadow that goes in and out with me,
And what can be the use of him is more than I can see.
He is very, very like me from the heels up to the head;
And I see him jump before me, when I jump into my bed.

The funniest thing about this is the way he likes to grow—
Not at all like proper children, which is always very slow;
For he sometimes shoots up taller like an india-rubber ball,
And he sometimes gets so little that there's none of him at all.

Robert Louis Stevenson (1906)

Afterward the children talked about the parts of the poem they liked best and why. Laura told the children that during science, for the next two weeks, they would learn all about light and shadows like those in the poem. Next, Laura gave the children a list of vocabulary terms they would use in learning about light and shadows.

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The children used the glossary in the back of their texts to find the definitions for the words (e.g., *light*, *reflection*, *transparent*, *translucent*, *opaque*, and *shadow*) and wrote them in their learning logs.

When finished with the vocabulary lesson, the class read aloud and discussed the chapter on sources and behavior of light from their textbooks. Now it was time to do several hands-on activities. The first activity demonstrated how light travels in a straight line. In the second activity, the children used flashlights, clear plastic, wax paper, and a book to demonstrate the meanings of the terms *transparent*, *translucent*, and *opaque*. Next, the students completed a worksheet showing a flashlight in four different positions and the resultant shadows cast by a small post. Then they used a flashlight and a short straw to duplicate and verify each diagram. In the final lesson, the students wrote a story entitled "My Friend the Shadow."

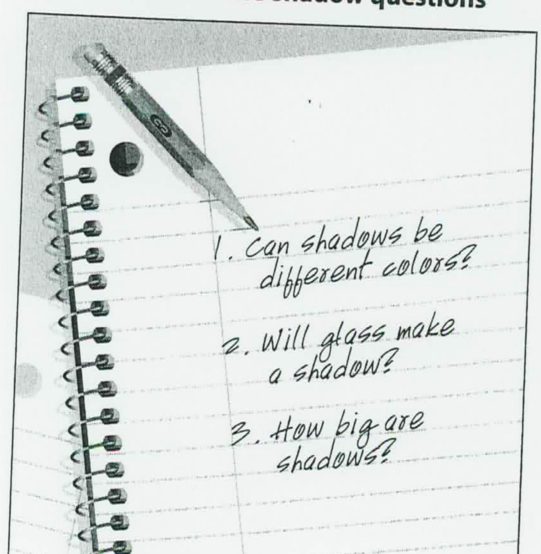
CARLA'S SECOND GRADE CLASSROOM

Down the hall, in the same school, Carla and her second graders were ready to begin their unit, "Light and Shadows." With the children gathered around, Carla read aloud the poem "My Shadow." After finishing the poem, Carla asked the children a number of questions: "What do you think it means when it says that sometimes my shadow is very tall and sometimes it gets little until there is none at all? Where and when have you seen your shadow look like this? What makes your shadow get long? Why does it sometimes get very small? When don't you have a shadow? Why? What do you need to make a shadow?" After finding out what her students already knew about shadows, Carla said, "What other questions do you have about shadows? Let's make a list of all of your questions and put them in our learning logs." (See Figure I.1.)

Investigating Shadows

The following day, Carla asked the children: "How could we make shadows and make them change? Do you suppose we could find answers to your questions from

Figure I.1 Children's shadow questions



yesterday? Let's try it and see." Carla divided the class into groups and gave each group a flashlight, a small lump of clay, a short section of drinking straw, and a large sheet of paper. The students explored the following questions: "How can you make a long shadow? What can you do to make a short shadow? How can you shine the light so there is no shadow at all? How can you make a shadow that points left? Right? Have your partner turn out the light and point it at the straw. Predict where and how long the shadow will be when the light is turned on." Carla asked the children to keep a record of all investigations in their learning logs. The students measured shadows using a ruler. When the activities were completed, Carla and the students discussed each question and the results, and then worked together to develop explanations for what happened.

Developing Conceptual Understanding

After several days, Carla then asked, "What do you think would happen if we put clear plastic, wax paper, or a book in front of our flashlights and tried to make shadows?" After listening to the children's predictions and explanations, she said, "Would you like to try it?" The students then gathered their materials and explored the problem. After finishing these investigations, Carla and the students discussed the terms *light*, *shadow, transparent, translucent,* and *opaque,* referring to their questions and explorations. The children developed a definition for each term and compared their definitions to the glossary in their text.

> *Science Background*
>
> In this activity, students work with various objects to determine if they make a shadow. There are some objects through which light is unable to pass. These *opaque* objects form shadows. Objects, such as clear plastic, that you can see through (because light is able to pass) are referred to as *transparent*. Objects, such as wax paper, that block part of the light passing through them are known as *translucent*.

Next, Carla selected relevant pages in the "Light and Shadows" chapter in their text. After reading these passages, Carla and the students compared what they had read to what they had done with the flashlights and straws. They compared the flashlights and straws to the sun and opaque objects. The next day the students traced their own shadows with chalk on the outside play area, then predicted where and how large their shadows would be later in the afternoon (verifying their predictions later). To conclude the unit, each child wrote and illustrated a story entitled "What Makes My Shadow Shrink and Grow?"

COMPARING THE CLASSROOM SCENARIOS

Consider the descriptions of the science lessons conducted by Laura and Carla. Although both scenes are brief and incomplete, nonetheless they provide a window through which to view two different learning environments. Compare them for the type of physical and mental processes required in learning the science content: (1) In which class were hands-on investigations designed around scientific questions generated by both the teacher and the students? (2) In which class were explanations based upon evidence gathered through observations and measurement? (3) In which class did students acquire information organized and presented by the teacher? (4) In which class did students use their curiosity to generate ideas, and means to test those ideas?

HOW DID YOU LEARN SCIENCE?

Reflect for a moment on how you learned science in elementary, middle, and high school. Your view of science today is most likely a reflection of how you learned it. Was your experience like that in Laura's class, or that in Carla's class? Students in Laura's class, and in many other classrooms

today, are learning science in a passive way: Information is organized and presented to them by their teacher. Often, the teachers pay little attention to what students already know about science. In this learning model, the information transmitted by the teacher and the curriculum materials is assumed to make sense and seem reasonable to the students. Each of us, however, has listened to many well-organized and articulated explanations that we did not understand. Even though we recognized and could probably spell each word, there was no way that we could explain what we had heard to someone else.

Two Views of Science

As a result, most of us view science from a very limited perspective. This perception of science has been influenced by the manner in which we studied it. Thus, we may see science as only an organized body of information about the natural world. Or, we may see science as a collection of terms and definitions—a body of knowledge to be memorized. Or, we may see science as the dynamic interaction of thought processes, skills, and attitudes that help us develop a richer understanding of the natural world and its impact on society. The latter view sees science as not just a body of knowledge but rather a "process for producing knowledge" (American Association for the Advancement of Science, 1990, p. 2). This view of science is the one that scientists, science educators, and many science teachers have today.

Impact of Science

The impact of science on our lives has never been greater. Each day, advances in science and technology affect the quality of our food, water, medicine, consumer products, and safety. To assume that science's impact will always be positive, however, is naïve and potentially foolish. As more people in the world demand newer products and access technology to produce them, it becomes increasingly important that we better understand how science, technology, and society are related. Thus, it is critical that our society be scientifically literate—have the day-to-day knowledge needed to make informed decisions about science and technology. The road to a more scientifically literate society begins with the opportunity for all students to develop a better understanding of fundamental science concepts, principles, and ways of thinking.

Like Scientists, Children Are Curious

Children seem to have an unending supply of questions about things around them: What makes my shadow grow longer? How do fish breathe under water? Why does the moon change its shape? What happened to the dinosaurs? Children are innately curious. This curiosity is a powerful stimulant for learning. Unfortunately, in many schools, curiosity is not valued. Students are not encouraged to ask questions like those listed above. They are more likely to be involved in lessons where they simply follow the directions of the teacher or text as if they were following a recipe in a cookbook.

A CLOSER LOOK AT INQUIRY AND THE NATIONAL SCIENCE EDUCATION STANDARDS

One major reform effort of the 1990s was the development of the National Science Education Standards (*NSES*), a broad effort that included hundreds of scientists, science educators, and teachers. The *National Science Education Standards* (National Research Council, 1996, p. 20) emphasize that learning science is an active process. "Learning science is something that students do, not something that is done to them." Doing science requires students to be involved in both the physical and mental processes collectively known as *scientific inquiry.* This implies that "hands-on" science activities alone are not enough. Students must have their "minds-on" as well. Clearly, the children in Laura's class were engaged in physical activities. Because they were merely confirming (verifying) what they had already read or been told, however, their minds-on quotient was significantly less than that of the children in Carla's class. Recall, Carla's students were performing physical activities designed to answer some question(s) and thus they were more mentally engaged.

Inquiry as a Process in Science

Student inquiry in science should mirror the active physical and mental processes conducted by scientists themselves. Employing inquiry in science classrooms requires a shift from teachers organizing and presenting content to active student involvement in investigations driven by scientific questions. Recorded observations and measurements provide students with evidence upon which to develop explanations, or answers to these questions. During science investigations, students make connections between their current knowledge and the recognized scientific explanations found in textbooks and other sources. The children can then apply this understanding to new questions, and communicate this knowledge to others.

Inquiry as Content in Science

The developers of the *National Science Education Standards* took a unique position with respect to school science inquiry. They viewed scientific inquiry as more than just a way to teach and learn science. In their judgment, scientific inquiry also involves an understanding of how scientific inquiry results in the continuing development of scientific knowledge. Therefore, they designated scientific inquiry as a content standard along with more familiar subject matter content areas: physical science, life science, and earth and space science. The *NSES* state, "As a result of activities in grades K–12, all students should develop . . . abilities necessary to do scientific inquiry [and] . . . understandings about scientific inquiry" (National Research Council, 1996, p. 105).

Inquiry abilities. This inquiry standard includes specific abilities necessary for students to do inquiry. Because inquiry abilities are actually mental processes, they become more complex as students mature cognitively. Compare the inquiry abilities (Figure I.2) for students in grades K–4 with those for students in grades 5–8 (National Research Council, 1996, pp. 122, 145, 148).[1]

Note that K–4 students "employ simple equipment and tools to gather data," while 5–8 students should also be able to "analyze" and "interpret" data. K–4 students should be able to "use data to construct reasonable explanations," while 5–8 students should be able to "recognize and analyze alternative explanations and predictions." These processes require students to use more sophisticated tools and critical thinking to engage with scientific inquiry. This increasing complexity of inquiry abilities mirrors the growth in cognitive development of students. As can be seen from Figure I.2, the developers of the inquiry content standard emphasize that employing these cognitive abilities requires the learner to go beyond typical science process skills such as observing, classifying, predicting, and experimenting.

Developing inquiry abilities requires active and thoughtful participation in science investigations. Although students are naturally curious and continually ask questions, they must learn the difference between broad, general questions and scientific questions. They need help in learning how to refine and focus questions about objects or phenomena that can be answered from evidence.

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[1]What does scientific inquiry look like in the classroom? The addendum to the *National Science Education Standards* focusing on inquiry (National Research Council, 2000, p. 25) describes what they term the *Essential Features of Classroom Inquiry*.

Essential Features of Classroom Inquiry

- Learners are engaged by scientifically oriented questions.
- Learners give priority to evidence that allows them to develop and evaluate explanations that address scientifically oriented questions.
- Learners formulate explanations from evidence to address scientifically oriented questions.
- Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
- Learners communicate and justify their proposed explanations.

Figure I.2 Inquiry abilities

Grades K–4: Abilities necessary to do scientific inquiry	Grades 5–8: Abilities necessary to do scientific inquiry
Ask a question about objects, organisms, and events in the environment.	Identify questions that can be answered through scientific investigations.
Plan and conduct a simple investigation.	Design and conduct a scientific investigation.
Employ simple equipment and tools to gather data and extend the senses.	Use appropriate tools and techniques to gather, analyze, and interpret data.
Use data to construct a reasonable explanation.	Develop descriptions, explanations, predictions, and models using evidence.
	Think critically and logically to make the relationships between evidence and explanations.
	Recognize and analyze alternative explanations and predictions.
Communicate investigations and explanations.	Communicate scientific procedures and explanations.
	Use mathematics in all aspects of scientific inquiry.

Experience in designing and conducting scientific investigations followed by reflective discussions of the mental and physical processes involved enable students to develop the idea of a fair test. Inexperienced investigators do not always discriminate between observations or measurements to know which data they should use to answer their question. The goal is to help students develop the ability to think critically—to analyze data and form logical explanations based upon cause-and-effect relationships in their investigation. Central to developing these physical and mental processes is helping students understand the "evidence to explanation" nature of scientific inquiry that sets it apart from other ways of thinking. If this is a new idea for you as well, be assured that working through the learning cycle lessons in this text will enable you also to enhance your ability to use observations and data from experiments to develop explanations for natural phenomena.

Inquiry understandings. To this end, the *NSES* (National Research Council, 1996, p. 123) also include what are known as the "inquiry understandings." These understandings parallel the inquiry abilities but also extend them to include how scientists create new knowledge through inquiry. They also reveal how scientists modify their explanations of natural phenomena as they present and debate new evidence and reasoning through publication and peer review.

Inquiry in the Classroom

Return to the snapshots describing teaching and learning in the classrooms of Laura and Carla. Examine each for the presence of the inquiry abilities. Which classroom scene demonstrates classroom inquiry? Students conducted investigations in both classes. In Laura's class, the investigations followed explanations provided by the teacher and instructional materials. The investigations were designed to verify explanations provided by others. Carla's students were given the opportunity to raise questions about light and shadows based upon their prior understanding. They designed and conducted investigations to answer their questions. The answers or explanations were constructed from evidence gathered from observations and measurements. The students then compared their explanations to accepted scientific explanations presented in readings from their text. Carla's students then defended their knowledge by writing and illustrating a story explaining the cause and effect of light and shadows. Employing science as inquiry helped Carla's students understand the cause-and-effect relationship of light and shadows, in much the same way as scientists had done before them.

NSES FOR TEACHING STANDARDS

To this point we have treated the topic of inquiry from the perspective of what children should understand and be able to do. What implications do these learning outcomes have for how teachers teach science? Just as there are science content standards for inquiry, there are also science teaching standards (National Research Council, 1996, pp. 27–53). These teaching standards are comprehensive and include many different teaching strategies, among them inquiry. Teaching Standard A states: "Teachers of science plan an inquiry based science program for their students" (National Research Council, 1996, p. 30). The *NSES* emphasize that effective teachers use multiple strategies. They point out that hands-on science activities do not necessarily result in students developing inquiry abilities and understandings. Instead, a variety of teaching strategies, including inquiry, are found to be most effective in helping students learn with understanding. This text provides a series of student investigations that use inquiry pedagogy coupled with teaching tips and other strategies consistent with the above standards. As you work through the investigations in this text, you will experience several of these different teaching strategies, which are integrated into the science lessons.

EARLY ADVOCATES OF INQUIRY TEACHING

Inquiry teaching and learning is not a new idea. It has not always been called *inquiry*, but the idea has been around for about a century although its popularity has been cyclical. In the early 1900s, science was taught in a passive mode, generally focusing on nature studies. Learning was generally limited to the acquisition of information presented by the teacher and through readings. We now turn our attention to four prominent learning theorists and their contributions to inquiry.

John Dewey

Around 1910, John Dewey appeared on the scene as a prominent advocate of reasoning rather than of memorization (Dewey, 1910). Dewey believed that instruction, particularly in science, should emphasize inquiry through problem solving. He also believed that students, when engaged in solving interesting and relevant problems, learned more effectively. He proposed that when challenged by a meaningful problem, learners actively reflect on what they already know from earlier experiences deemed similar in nature. After actively comparing and contrasting ideas, the learner begins to form a reasonable hypothesis or explanation to be tested.

Dewey emphasized the importance of providing problems that are personally relevant and interesting for the learner. Consequently, concepts or problems deemed important by the teacher and the curriculum are not always sufficient, in Dewey's view. Dewey believed that, to effectively engage meaningful thought processes, learners had to perceive problems as *personally interesting and relevant to daily events and experiences* in their world. Dewey also felt that enabling students to interact with each other, comparing their thoughts and ideas, was extremely important.

Jean Piaget

From 1920 until late in the 1970s, the contributions of Jean Piaget heavily influenced the field of cognitive development. This Swiss biologist was intrigued with what he perceived as the progressional development of mental structures that influence thinking in children. Although Piaget did not address inquiry specifically, one could argue that his views on the mental processes involved in learning are directly related to the concept of inquiry. Piaget viewed learning as an active process in which the learner compares and contrasts modes of thinking about new experiences with those of prior experiences. Often the child realizes that the explanation used for an earlier experience just does not seem to fit with a new experience. This results in a

kind of puzzlement Piaget referred to as *cognitive disequilibrium*. To resolve this type of problem, learners may need to modify their way of thinking to come to a conclusion that seems personally reasonable. Piaget called this process of thought adjustment *equilibration* (Inhelder & Piaget, 1958).

The process of equilibration has unique and important implications for the teaching of science (Bybee & Sund, 1982). Equilibration is the process through which children learn by altering or adapting a mental structure. This adaptation occurs through two active thought processes, assimilation and accommodation. *Assimilation* occurs when learners compare the new experience (and its explanation) with an earlier one and decide the two are very similar. The new experience is then incorporated or assimilated into the already-existing mental structure. When learners encounter an experience for which they have no preexisting mental structure available for assimilation, the mind adapts by changing its thought processes and adding a new mental structure. This process is known as *accommodation*. For example, suppose some of Carla's students believed that all solid objects cast shadows. During one of the investigations, they place a small card-shaped piece of clear plastic in front of a flashlight and one of them shouts, "Look, there's no shadow! Where did it go?" How might the students deal with this discrepant event? If the problem were truly perplexing to them, and they were encouraged with probing questions to explore and test it further, the students might accommodate the problem of the clear plastic by constructing a new understanding about how a transparent object creates essentially no shadow.

Assimilation and accommodation are dynamic processes and occur together rather than in isolation. Learning through equilibration requires that learning be an active process, like that described in the *National Science Education Standards*, in which students are involved in both hands-on and minds-on investigations.

Lev Vygotsky

Vygotsky was a Russian psychologist who died at the age of 38. At a very young age, he became interested in developmental psychology after a period in medical and law school. Vygotsky was especially interested in social interactions and their influence on cognitive development. He noted that "Culture creates special forms of behavior, modifies the activities of mental functions and adds new stories to the developing system of human behavior" (Vygotsky, 1966, p. 19). Vygotsky is probably best known for his concept of the *Zone of Proximal Development*, which he defined as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1978, p. 86). In other words, Vygotsky believed that a student's learning development is facilitated by social interaction with more sophisticated individuals that provide guidance during the learning process. From Vygotsky's work, we can see that the value of students working in small groups to conduct science investigations comes from the discourse that takes place. It also follows that the skillful intervention of a teacher can elevate the level of students' thinking and learning.

Jerome Bruner

An exceptionally bright young man, Bruner was educated at Duke University and Harvard. He became intrigued with psychology and focused on the study of how people learn. Bruner contended that learners should not spend their time *talking about* science, they should be *doing* science. Much of his learning research centered upon *active-discovery learning through inductive reasoning*. Inductive approaches involve the use of specific concrete experiences in which the learner organizes objects and events to discover patterns and relationships, then develops solutions or explanations (Bruner, 1960).

The work of Dewey, Piaget, Vygotsky, and Bruner has contributed significantly to both elementary and middle-level science curriculum development and approaches to teaching science. Their theories of intellectual development and how students learn provide the foundation for what the *NSES* refer to as *active-learning through inquiry-oriented investigations*.

Implications for Instructional Materials

The United States during the 1950s and 1960s saw large-scale efforts that deliberately moved away from passive learning approaches. Locked in a race with Russia to land people on the moon, the nation felt the need for citizens who better understood not only science concepts and principles, but also the nature of science and how it works. In response, governmental agencies, primarily the National Science Foundation, and private foundations provided funds for the development of new elementary and secondary science curricula that emphasized learning through inquiry. Three large-scale programs were developed for elementary school classrooms. The *Science Curriculum Improvement Study* (SCIS), the *Elementary Science Study* (ESS), and the *Science—A Process Approach* (SAPA) each involved children in *active* physical and mental processing of questions and problems through science investigations. SCIS and ESS, in particular, emphasized developing an understanding of concepts and their cause-and-effect relationships. Terminology and definitions were constructed from the active hands-on and minds-on experiences of the children. New, more inquiry-oriented programs were also developed for junior high and high school students. Funds were also made available for teacher in-service and professional development.

Implications today. While research showed that students in the new elementary science programs understood science concepts better than did their counterparts who were taught in more-passive environments, the acceptance of programs like ESS, SAPA, and SCIS was disappointing and short-lived for the most part (Bredderman, 1982; Harms & Kahl, 1980). Many classroom teachers who learned science by acquisition of information apparently found it difficult to teach using inquiry approaches and strategies. Others have argued that elementary school teachers did not have sufficient time and support to maintain instruction in these programs. The long-term impact of these programs, however, has been significant. Influenced by the philosophy and approach guiding the new programs, teachers and instructional materials developers began using more hands-on laboratory activities in their classrooms. A shift from using activities to verify concepts to that of investigating first became more common. Modifications of ESS, SAPA, and SCIS investigations made their way into laboratory manuals and textbooks. The focus on inquiry began to take shape and formed the backbone for the National Science Education Standards and the recommended science teaching and learning methodology.

HOW LEARNERS CONSTRUCT MEANING

Misconceptions

Earlier we asked you to reflect on how you learned science in classes you had taken from elementary school through college. Our premise was that most of us learned through instructional models patterned after time-honored practices in passive learning. These approaches have come under close scrutiny for a number of reasons. While it is true that the general public holds many misconceptions about science, a surprising number of college science majors as well as graduate students also demonstrate a lack of understanding of basic scientific concepts (Bodner, 1991; diSessa, 1982; Meltzer, 2004). Their explanations of certain fundamental concepts are inconsistent with accepted scientific explanations and, thus, are referred to as misconceptions. This finding is a bit disconcerting when you consider that these young men and women were highly interested in the study of science and deliberately chose to study it! It emphasizes, however, the need to provide students with lots of hands-on experiences and minds-on thinking to steer them toward more-accurate understandings of science concepts and principles.

Common misconceptions. The following is a list of common misconceptions held by high school students (Hapkiewicz, 1992). Read through the list and think about your own understanding of each statement.

- Earth's seasons are caused by the distance from Earth to the sun.
- The phases of the moon are caused by Earth's shadow covering up different parts of the moon.

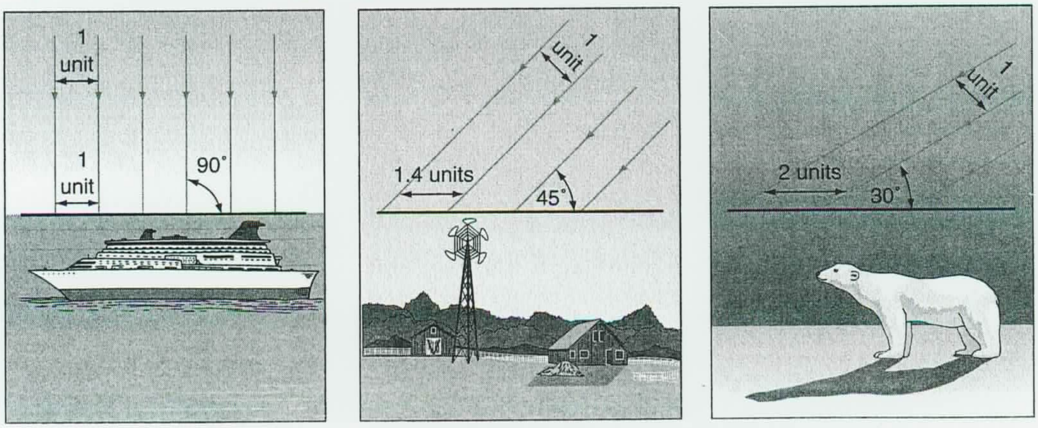
- Heat rises.
- Electrical current in a flashlight flows from the battery to the bulb, not from the bulb to the battery as well.
- All metals are attracted to magnets.
- The bubbles in boiling water contain hydrogen and oxygen.
- Objects float in water because they are lighter than water.
- If you back away from a mirror, you can see more of yourself.
- The sun is directly overhead at noon each day.

Adults' misconceptions. In all probability you have, in various science courses in your schooling, studied most of the topics covered in this list of misconceptions. Many of you also will undoubtedly share some of the same misconceptions. If you are feeling a little uncomfortable with your thinking on several of these examples, you are in good company. In a video entitled *A Private Universe* (Pyramid Film and Video, 1988) 23 graduating Harvard seniors, alumni, and faculty were interviewed to find out their understanding of simple astronomy questions related to seasons and the phases of the moon. Twenty-one of the 23 gave explanations that exhibited misconceptions. For example, they stated that Earth's seasons were the result of its distance from the sun—winter occurring when the Earth was farther away and summer when closer. It is reasonable to assume that each of these educated persons had, at some point in their schooling, received formal instruction about this concept. The distance between the Earth and the sun has virtually nothing to do with why we have seasons. In fact, the Earth is slightly closer to the sun during the winter season in the northern hemisphere. The relationship between the tilt of the Earth on its axis as it revolves around the sun and the angle at which solar energy strikes Earth's surface, however, directly affects the amount of energy absorbed, producing the seasons (see Figure I.3).

Children's misconceptions. Elementary school children, naturally, exhibit similar misconceptions. Particularly interesting is the fact that, even after completing units of study in science, many children still do not change their explanations. These *naive* or *alternate explanations*, or *misconceptions,* seem to persist in spite of direct instruction in the concepts. For example, Beverly Bell, a New Zealand researcher, found that a surprising number of children ages 6 through 12 when queried about plants and animals did not classify grass, carrots, or oak trees as plants (Bell, 1981). Whereas most adults tend to classify living things into two general groups, plants and animals, children often use different reasoning and construct different systems for classifying these living things.

Science and misconceptions. Since the emergence of modern science, the understanding of basic concepts explaining the behavior of objects and events in the universe was obtained through inquiry. Scientists pursued intriguing questions and problems through active exploration. They

Figure I.3 The sun's energy is spread over a wider area of earth as its angle decreases



tested their hypotheses and compared results with what was known at the time. When data were not consistent with their hypotheses, they tried different ways of thinking about the phenomena until reconstructed explanations began to make sense and could be verified through further testing. This is what actually distinguishes modern science from previous ways of explaining phenomena. This may explain why geocentric (earth-centered) explanations of the solar system persisted for thousands of years—even in light of many observations to the contrary.

Constructivism

Cognitive psychologists and science educators, influenced by the work of misconception researchers, have added much to the work of early discovery learning advocates. What follows is a blend of ideas from Dewey, Piaget, Vygotsky, and Bruner together with more-recent findings. Underlying this research is the notion that all people normally try to make sense of their world. Although most of us operate with far less precision than does a scientist, we still seek to explain, predict, and control our experiences.

Revisiting Laura's and Carla's classrooms. Let's begin by reconsidering the scenarios presented earlier regarding the teaching of light and shadows. Recall that in Laura's classroom:

> Laura gave the children a list of vocabulary terms they would use in learning about light and shadows. The children used the glossary in the back of their text to find the definitions for the words (e.g., *light*, *reflection*, *transparent*, *translucent*, *opaque*, and *shadow*) and wrote them in their learning logs. When finished with the vocabulary lesson, the class read aloud and discussed the chapter on sources and behavior of light from their textbooks.

This teaching methodology assumes that knowledge can be transferred directly from the textbook to the student—in the manner one would download information from a computer. Indeed, this method works with some students—those whose prior experiences allow them to make sense of the new information. For many students, however, the new information will be difficult to understand, and to some it will be meaningless!

In contrast, let's look once again at Carla's classroom:

> After finishing these investigations, Carla and the students discussed the terms *light*, *shadow*, *transparent*, *translucent*, and *opaque*, referring to their questions and explorations. The children developed a definition for each term and compared their definitions to the glossary in their text. Next, Carla selected relevant pages in the "Light and Shadows" chapter in their text. After reading these passages, Carla and the students compared what they had read to what they had done with the flashlights and straws.

In this case the students began by exploring shadows through a series of inquiry activities using a variety of materials. From these experiences they developed their own understandings of the concepts. Not until after this did Carla provide the accepted scientific vocabulary and have students read their text. Note that in this method the teacher facilitated the students' construction of their own understandings. A broader range of students will more likely be able to make sense of information when it is presented in this manner (Shymansky, Kyle, & Allport, 1983).

Constructing meaning. Students are not always ready to receive or absorb incoming information as presented by their teacher or textbook. Nor do they "discover" concepts just by manipulating hands-on materials. Instead, when students are challenged by something they want to learn, they try (with varying degrees of success) to consider any incoming data in the light of related information already stored in their long-range memories from previous experiences. In other words, they *construct* new meanings by combining incoming information with what they already know. This view of learning is called *constructivism.* The basic premise of constructivism is that learners receive sensory input, compare it to existing memory networks of what appears to be a similar event, modify if necessary, and then construct explanations that seem to make sense. What learners actually construct from a given learning experience varies from student to student and often deviates from what the teacher intended. Constructivists contend that there is no "fiber optic cable" from one person's mind to another. This means that one person's understanding of a concept does

not necessarily transmit as personal understanding to the person receiving the information. The learner *always* personally constructs understanding.

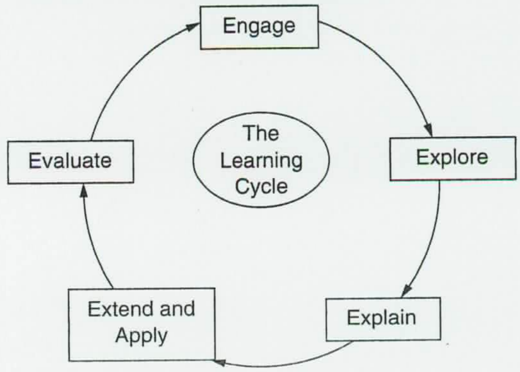
Inquiry Learning Models

Constructivists believe that effective instruction depends on our ability as teachers to understand how students make sense of experiences and information rather than how we make sense of those same experiences ourselves. The ideas of Dewey, Bruner, Vygotsky, and Piaget on how children develop an understanding of their world have a common thread. Each of these researchers suggests that effective learning involves an interesting problem or situation that engages students through reflection on what they already know about the event. If the problem is unique, the students' prior knowledge does not help provide a satisfactory explanation. Piaget proposed that such discrepant events cause learners to experience disequilibrium. There is a discrepancy between what they think they know and what they are observing. "To bring their thinking back into equilibrium they must adapt or change their cognitive structure through interaction with the environment" (National Research Council, 2000, p. 34). In classrooms, this interaction with the environment is facilitated by investigations designed to gather evidence that supports a newly discovered explanation. This approach is central to teaching and learning through inquiry. Contemporary science educators support the premise that inquiry approaches to learning are more effective in promoting the understanding of concepts (Loucks-Horsley et al., 1990).

The Learning Cycle. Instructional models provide a consistent framework to help teachers become more effective in using inquiry approaches. One widely accepted model of learning and teaching has evolved over the past 40 years. This model is referred to as the *Learning Cycle*. Influenced by the work of Jean Piaget, Professor Robert Karplus, at the University of California–Berkeley, began looking at how one might apply cognitive development theory and discovery learning to instructional strategies in elementary science. Karplus and his colleague, J. Myron Atkin, with the support of the National Science Foundation, developed a three-phase Learning Cycle that served as the central teaching/learning strategy in the newly introduced Science Curriculum Improvement Study (SCIS) program (Atkin & Karplus, 1962).

Originally, the three phases of the cycle were referred to as *exploration*, *invention*, and *discovery*. Later, Karplus referred to them as *exploration*, *concept introduction*, and *concept application*. The Learning Cycle (Figure I.4) has been promoted widely by science educators since its introduction by Karplus. The cycle has evolved through modification to include additional phases such as *engage, explore, explain, elaborate, extend,* and *apply* and is used to frame single guided discovery lessons as well as extended experiences such as chapters and units (Barman & Kotar, 1989; Hackett & Moyer, 1991). A fifth phase, *evaluate*, was incorporated into an elementary science program developed by the Biological Sciences Curriculum Study (Biological Sciences Curriculum Study, 1992). The learning cycle approach to discovery learning (see Figure I.4) is developed more thoroughly in Investigation 1.

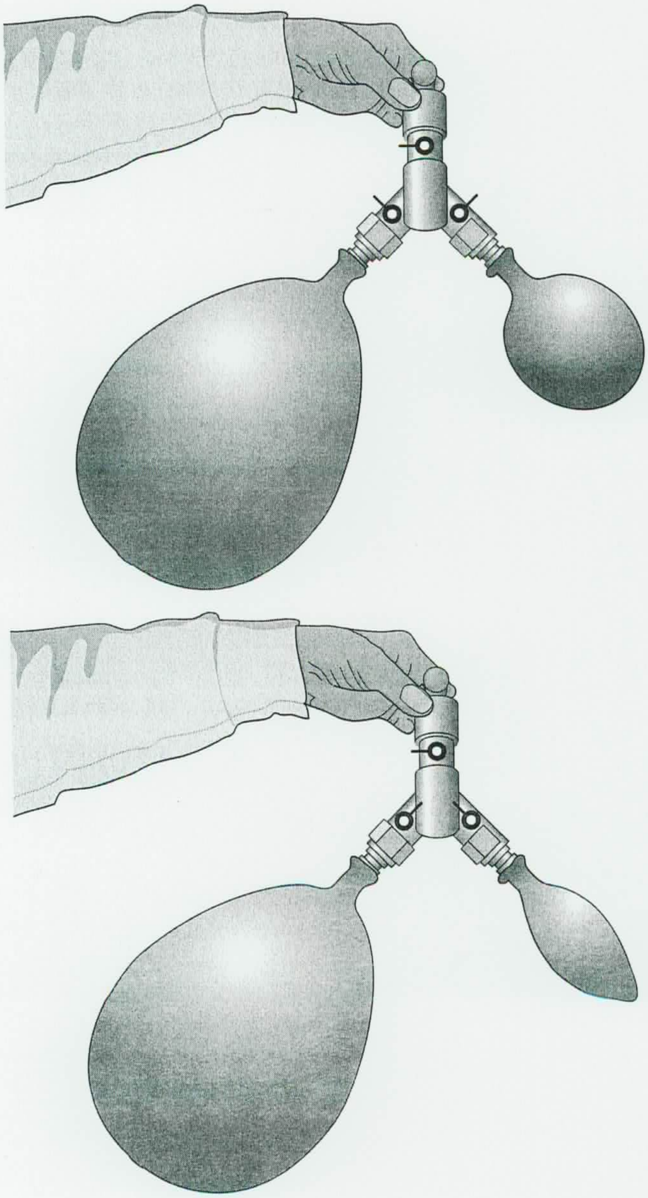
Figure I.4 The Learning Cycle



Teaching for conceptual change. The Learning Cycle has been further modified to address student misconceptions (Driver, Guesne, & Tiberghien, 1985). Rosalind Driver, in her work with elementary students, has investigated methods of instruction designed to help children confront previously developed misconceptions by comparing them with new experiences. She places great emphasis on providing opportunities for children to express what they already know—their prior understanding. The teacher must then structure new student experiences for situations in which the prior conception or explanation results in learner disequilibrium.

Discrepant events. One effective way to challenge student misconceptions is through the use of discrepant events (Friedl & Koontz, 2005). Discrepant events, as the name implies, are activities or demonstrations whose results are counterintuitive. Imagine the two balloons depicted in Figure I.5. What will happen if the valve is opened between the two balloons? Most people conclude that, because the pressure must equalize, air will then flow from the larger balloon to the smaller balloon, resulting in the two balloons becoming approximately the same size. But this is not what occurs! The pressure does indeed become equal, but air flows from the *smaller to the larger*

Figure I.5



balloon![2] At this point learners may well experience disequilibrium. The learners are motivated intellectually to investigate further.

Through further exploration, exchanging ideas with others, and restructuring thought through assimilation and accommodation, the learner constructs new understanding.

Using the Learning Cycle to address misconceptions. Identification of learner misconceptions becomes an important part of the *Engage* phase of the Learning Cycle. Student investigations designed to assist the learner in restructuring new understanding are the focus of both the *Explore* and *Explain* phases of the Learning Cycle. The intent of the *Extend* and *Apply* phase is to provide students with opportunities to transfer their reconstructed understanding of concepts to different situations. Emphasis should be on applications to situations and events in everyday living. This approach Driver calls *teaching for conceptual change*.

Conceptual change in a classroom. Following is an excellent example of a classroom teacher applying strategies of teaching for conceptual change. Deb O'Brien, a fourth grade teacher in Massachusetts, was about to begin a unit on heat (Watson & Konicek, 1990). Her original plan called for studying major heat sources and learning to use thermometers. Students were to finish the unit in about two weeks. O'Brien began by asking, "What is heat?" She and the students kept record of what they already knew about heat. It soon became evident that many of the children believed that sweaters, coats, and hats were hot. After all, they had heard parents repeatedly say, "It is going to be cold today, so be sure to wear your warm sweater." Deb suspected this was just one of several "naive conceptions" held by her students. She also felt sure that just telling them about the insulative properties of hats, coats, mittens, and sweaters would not be enough to alter their perceptions. So, she responded with the challenge, "Well, let's see if we can find out!"

Ms. O'Brien's students set about testing their ideas with simple experiments. They wrapped a thermometer inside a sweater and left it for 15 minutes. To the surprise of the students the temperature on the thermometer had not increased. "Well, it would have gone up if we had left it in there longer!" Next, they left their tests overnight. Again there was no temperature change. Puzzled by the results, some students suggested that somehow cold air must have gotten into the sweater. After all, the thermostat is turned down overnight! Further testing was performed, including sealing sweaters and hats in plastic bags and putting them in closets and drawers. One student even suggested sealing a sweater in a metal box for one whole year. That would make it heat up! Test data continued to be consistent with earlier experiments. After three days of testing, O'Brien felt the children had begun to face the idea that their old theory just didn't work. Now they were ready for discussions of where the heat in "hot" sweaters really comes from, heat flow from the source to a receiver, properties of insulators, and so on. The children had a series of new experiences that promoted reflective thinking, comparing, contrasting, and restructuring explanations. This approach actually resulted in conceptual change for most of O'Brien's students.

Findings from the Inquiry Addendum

After the National Science Education Standards (NSES) were published, the National Research Council formed a special committee of leading science educators to develop an addendum that focused on inquiry entitled *Inquiry and the National Science Education Standards* (2000). This document is based, in part, on a National Research Council report entitled *How People Learn* (Bransford, Brown, & Cocking, 1999), which brought together research results on cognition studies, child development, and brain function. Some of the major findings of the addendum are discussed below.

1. "Understanding science is more than knowing facts" (National Research Council, 2000, p. 116). Recent research has focused on learning for understanding. Learners who understand concepts can apply them in new situations. To do this learners must have a

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[2] The reason is that the pressure on the air in the balloons is caused by the elasticity of the balloons. Because the latex is thicker in the smaller balloon, the pressure on the air is greater. For this reason the first puff of air one blows into a balloon takes the most effort.

foundation of facts organized in a particular context in a manner that allows them to retrieve and apply them. In addition to understanding concepts, students need to develop abilities and understandings of scientific inquiry as described in the *NSES*.

2. "Students build new knowledge and understanding on what they already know and believe" (National Research Council, 2000, p. 117). This finding is supported by research related to how prior knowledge and conceptions influence learning. If these understandings are not engaged by investigations that provide evidence to help students restructure their reasoning, learners may hold fast to their old ideas and rely on memorization to help them pass tests.
3. "Students formulate new knowledge by modifying and refining their current concepts and by adding new concepts to what they already know" (National Research Council, 2000, p. 118). Research on conceptual change shows that students are more apt to change their explanations when they find that their initial ideas do not help explain what happened in a given event (from Driver et al., 1985).
4. "Learning is mediated by the social environment in which learners react with others" (National Research Council, 2000, p. 118). A classroom learning environment where students defend explanations that they have derived from evidence enhanced learning. This environment is consistent with learning science through inquiry.
5. "Effective learning requires that students take control of their own learning" (National Research Council, 2000, p. 119). Learning through inquiry can help students recognize when they do not understand and need additional information or evidence. Teachers can assist students in these processes by consistently helping them reflect on the processes involved in constructing understanding.
6. "The ability to apply knowledge to novel situations, that is, transfer of learning, is affected by the degree to which students learn with understanding" (National Research Council, 2000, p. 119). Students who are very successful at learning through acquisition are not necessarily good at applying this knowledge to other situations. Memorizing terms such as *heat*, *evaporation*, or *photosynthesis*, for examples, does not guarantee that the learner can apply them to events in the natural world. This fact may be especially evident to science teachers who can easily define such terms, but find it difficult to answer students' questions regarding application of the concepts in nature.

Summary

How effectively we teach children science is linked to our understanding of how children learn. Ideas proposed by early cognitive researchers like Dewey, Vygotsky, Piaget, and Bruner provide us with insight into teaching and learning through inquiry. Children are ruled by their perceptions, and so our ability to help them construct meaningful explanations for events in their world is critical. Children, as well as adults, appear to derive meaning from experiences by reflecting and constructing on what they already know. Learning proceeds by fitting new information into an existing schema (assimilation), and modifying or forming a new schema (accommodation). Because an existing schema may either help or hinder new learning, teachers must be aware of such knowledge so they can plan suitable lessons to help students develop explanations consistent with accepted scientific knowledge. Skillful teaching can help children build organized structures of related information in their

Teaching Tip

Inquiry Teaching

In the following Investigations you may want to refer back to this introduction as you learn more about inquiry pedagogy. As you do so, you may also wish to consider how the authors chose to organize this section. Note that it begins with two vignettes describing classroom teaching. Based on these examples, we have developed some understandings regarding inquiry science teaching and the *National Science Education Standards* (NSES). This was a conscious choice to reflect the constructivist philosophy of this book rather than a more traditional didactic pedagogy. We chose not to begin with a definition of constructivist learning or inquiry followed by a listing of the NSES Inquiry Abilities and Teaching Standards, but rather developed those from the teaching examples. You will have additional opportunities to experience this model as you proceed through the text.

memories that improve their ability to retrieve and apply knowledge. It is fitting to close with the following quote:

> Learning science is something that students do, not something that is done to them. In learning science, students describe objects and events, ask questions, achieve knowledge, construct explanations of natural phenomena, test those explanations in many different ways, and communicate their ideas to others. (National Research Council, 1996, p. 20)

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